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Investigation of the Stress-Strain State of the Cavity Profiles for Osteosynthesis Screw Heads

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Abstract. In the modern world, taking into account the active lifestyle of people, the dynamics of growth of complex fractures is observed. Their treatment is associated with rigid fixation of fragments with plates and screws, that is, with the help of osteosynthesis. In the surgical operating room during osteosynthesis is not possible to use auxiliary tools, which can be used to fix the screw with the required screw-in force. As a result, the screw breaks either during surgery or during further operation. This can be avoided by examining the stress-strain state of the screw head for osteosynthesis. By simulating the screw turning process, it is possible to determine the maximum stresses appearing in the screw heads with different profiles, and to choose or develop the profile of the recess under the key, which will be optimal in terms of stress-strain state and manufacturability .

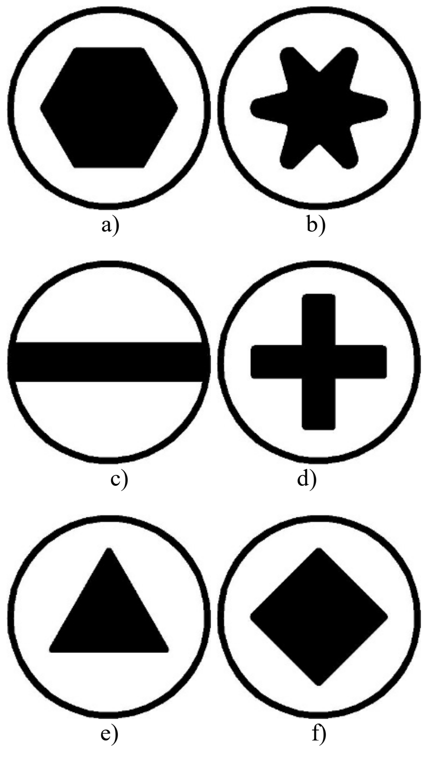
1 Introduction

The number of fractures of different degrees of complexity around the world is increasing every year. Meltona [1] showed that in Russia the number of patients with hip fractures alone will grow, according to World Health Organization forecasts, to 6 million by 2050, or by 300% compared to 1.5 millions in year 1990. This explains a growing demand on implants and other elements such as screws.

All existing developments and products in the field of fastening elements of screws for osteosynthesis are of foreign origin, and are made by "Zimmer" (international company), " Koenigsee" (Germany), " Double Medical" (China) and others. There are practically no modern domestic analogues of these products, and taking into account the fact that the share of Russian production in this market is about 5 % of the world market ("Osteosynthesis", " Osteomed", "TitanImplant"), this area, despite being quite promising, is yet to be developed.

Osteosynthesis is the prompt insertion of a retainer (plate) and its fastening with screws or screws for osteosynthesis [2, 3]. The main difficulty in a surgical operating room for this type of manipulation is the impossibility to use a special instrument, such as torque wrenches. This leads to a number of problems related to the fixation of osteosynthesis plates. If the osteosynthesis screw is not tightened enough during operation, it may unscrew and break, damaging the soft tissues in the fracture area. In case of exceeding the allowable tightening force - the screw may be damaged directly in the process of screwing, it leads to the fact that during the surgical intervention the surgeon will have to pull it out, install a new screw (if possible), thereby increasing the duration of the operation and the amount of anesthesia. In each of these two cases, the risks of additional harm to the patient health increase [4, 5].

One of the most common cases of osteosynthesis screw breakage is the buckling of the recess and breaking of the screw head. This is due to the stresses that occur in the screw head during the tightening process, which primarily depend on the keyhole profile. Fig. 1 shows standard profiles used in the manufacture of osteosynthesis screws.



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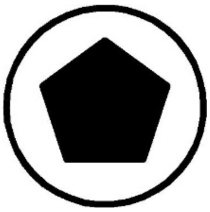


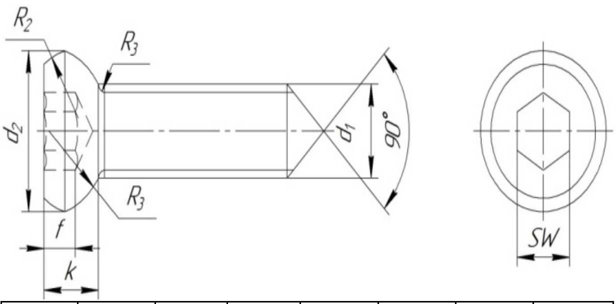
g)

Fig. 1. Standard screw head wrench recess profiles. a) hexagon; b) torx; c) flat slot; d) cruciform slot; e) triangle; f) square; g) pentagon

Despite such a variety of profiles, the problem of their buckling and breaking of the screw head still remains unsolved due to significant stresses and deformations.

The main goal of the study is to develop a turnkey depression profile that will reduce the number of screw breakages for osteosynthesis. To solve this problem, it is necessary to investigate the stress distribution inside the screw head in the process of screw turning , which can be obtained using three-dimensional modeling [6, 7].

In this study, the stress-strain state of the screw heads for osteosynthesis was simulated using standard types of turnkey recess profiles. The heads were modeled using SolidWorks software according to GOST R 50582 -93 (ISO 5 835-91) [8]. Since osteosynthesis screws with a nominal thread diameter of 3.5 mm are most often used, the heads with these parameters were modeled [9, 10] (Fig. 2).



d_1, mm	d_2, mm	f, mm	k, mm	R_1, mm	R_2, mm	R_3, mm	SW, mm
3,5	6	1,5	2,6	3	2,5	0,3	2,5

Fig. 2. Screw drawing for osteosynthesis GOST R 50582-93 (ISO 5835-91).

The diameter of the circle SW entered in the figure is selected as the main parameter that determines the size of the profile for the key screw head for osteosynthesis. The choice of material was determined taking into account the requirements to metal materials intended for use in production of surgical implants according to GOST R ISO 5 832-2-2014 [11]. Chemically pure titanium Ti was used as a material for modeling the stress-strain state of screw heads for osteosynthesis [12, 13].

2 Experiments

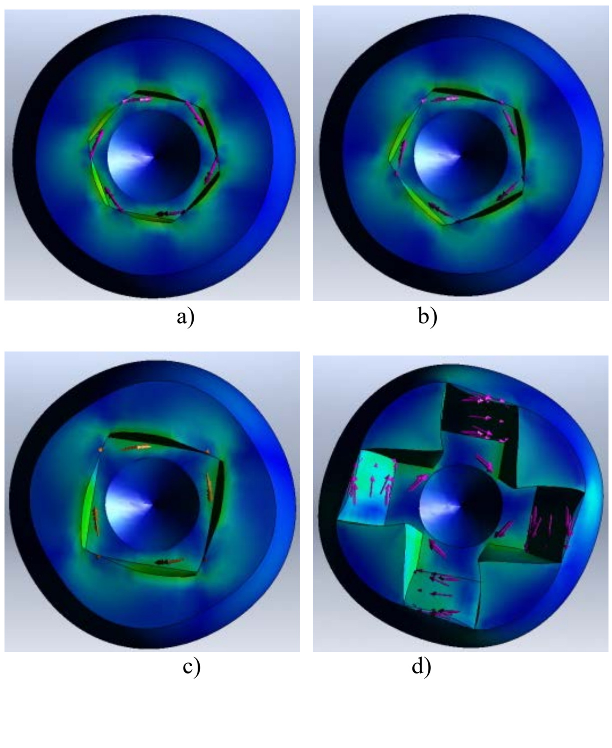
Cutting speeds of up to 400-500 m/s can be achieved by Stress on the keyhole profile of the head screw for osteosynthesis was taken for the reason that the average person when tightening the screw develops a torque of 3-5 N / m . In operation, stresses, deformations and displacements were calculated taking into account the applied 4 N/m torque. In this case, the load was applied evenly distributed on the contact surfaces of the profile of the recess under the turnkey screw head. As a result of the applied load in the body of the screw head for osteosynthesis there is a stress-strain state that determines the level of buckling and deformation of the recess profile. Simulation of the screw-in process for osteosynthesis allows to determine a rational profile in terms of stresses, deformations and movement. In fig. 3 shows the result of simulation using different standard profiles.

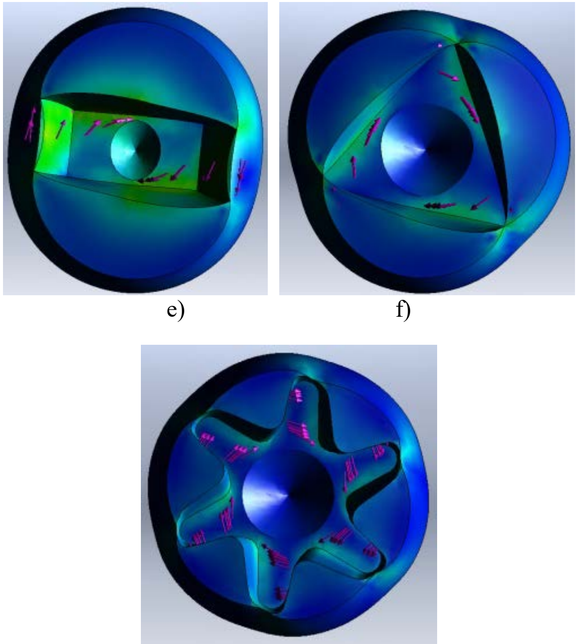
As a result of modeling for each screw head turn-key indentation profile the maximum values of stresses, displacements and deformations arising during the screw-in process are obtained (Table 1).

From the results obtained, we can conclude that the smallest stresses, displacements and deformations occur on pentahedral, hexagonal and square profiles and have the following values: maximum stress within σ = 1270.59-1296.16 MPa, maximum displacement e = 12.9-13.4 µm, maximum strain Δ = 0.0083-0.0091.

Table 1. Maximum values of stresses, displacements and deformations using different standard profiles

Profile form	Maximum stress, σ MPa	Maximum movement, e µm	Maximum deformation, Δ
Pentagon	1270,6	13,0	0,0083
Hexagon	1274,6	12,9	0,0091
Square	1296,2	13,4	0,0086
Cruciform slot	1314,5	14,5	0,0093
Flat slot	1411,3	24,9	0,0099
Triangle	1967,8	19,3	0,0099
Torx	1970,8	15,2	0,0106





e) f)

g)

Fig. 3. The result of simulation using different standard profiles; a) hexagon; b) pentagon; c) square; d) cruciform slot; e) flat slot; f) triangle; g) Torx

The practical implementation of these profiles shows unstable results in the installation of screws for osteosynthesis, i.e. there is a risk of breakage of the head of the screw for osteosynthesis as a result of buckling during their insertion and operation. In this case, in the manufacture of standard profiles of the recessed turnkey there are certain difficulties due to the fact that the existing process of manufacturing screws involves obtaining a turnkey profile by means of stamping operations, which causes the profile corners to be rounded. At the same time, the corresponding keys do not have such roundings, as a result of which this difference in the shape of the key and the key recess profile leads to an uneven distribution of stresses in the screw head. Also the shape of the keyhole profile of the head of the screw for osteosynthesis determines the contact area of the key with the profile. There is always a certain gap between the key and the key recess of the screw head. Because of this, the key is free running and the contact area between the key and the recess at the moment of applying the force required for screwing in the section is actually reduced to a point or a line. Therefore, if the torque created by turning the screw will be higher than allowed, the corners of the key will crush the profile of the recess in the screw head, causing it to be inoperable.

This is also a defining criterion in the distribution of voltages. That's why there was a need to create and study non-standard shapes of recesses with no sharp angles.

The analysis of existing shapes showed that of interest are such keyed indentations profiles for osteosynthesis screw heads as the Ryolo's triangle (the result of intersection of three circles, the figure of constant width) and the ellipse. Also in the work was built and calculated such a profile as a rounded triangle, which is also a figure of constant width.

The proposed profiles are distinguished by the use of radius curves, with the Ryolo's triangle, as well as standard profiles have angular shapes.

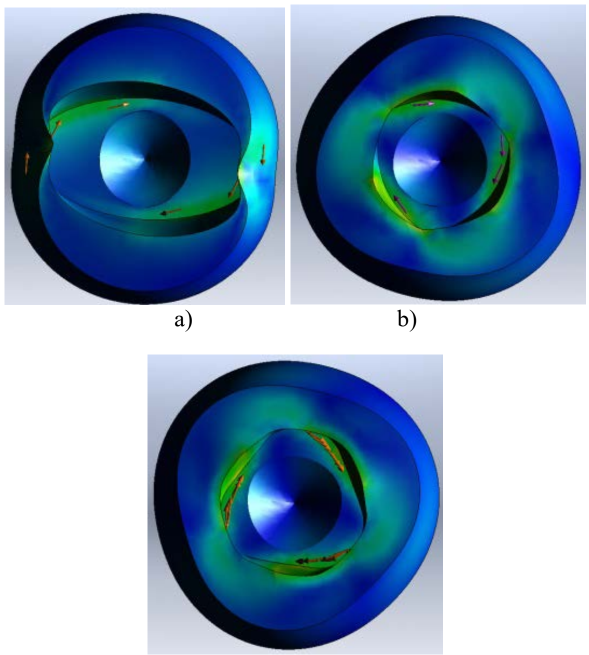
Three-dimensional modeling made it possible to determine stresses, deformations and movements in the proposed profiles. Modeling results are shown in Fig. 4 and in Table 2.

Table 2. Maximum values of stresses, displacements and deformations using various special profiles

Profile form	Maximum stress, σ MPa	Maximum movement, e μm	Maximum deformation, Δ
Rounded triangle	1309,46	13,67	0,0087
Ryolo's triangle	1249,64	13,47	0,0084
Ellipse	2185,40	32,65	0,0127

The use of turnkey profiles without sharp angles makes it possible to facilitate the process of manufacturing screws and improve their quality. The larger contact area between the key and the profile, compared to standard profiles, ensures an even distribution of stresses inside the screw head for osteosynthesis, thus reducing the number of breakages.

As a result of modeling of standard profiles it has been established that such profiles as square, pentagon and hexahedron are rational in terms of stresses, deformations and displacements. The values of maximum stress are within σ = 1270.59-1296.16 MPa.



a) b)

c)

Fig. 4. The result of modeling with the use of various special profiles. a) ellipse; b) Ryolo's triangle; c) rounded triangle

As a result of the simulation of special profiles, rational were such profiles as the Ryolo's triangle and the rounded triangle. The maximum stress values for these profiles are within σ = 1249.64-1309.46 MPa.

The experiment carried out with the help of three-dimensional modeling is ideal and the actual stresses created in real conditions in the screw head will be different from the calculated ones. This is because a person cannot insert the screw into the bone with the same force every time, it is also quite common for the key to the cavity to be installed with a distortion, resulting in a change of contact area and load distribution.

In order to make the calculations as close to real as possible, it is necessary to conduct a multifactorial experiment. The number of necessary experiments is calculated by formula $n = 2k$, where k is the number of factors. . The main factors influencing the tensions created in the screw head during the screwing-in process are the contact area between the key and the recess profile S (mm) and the torque generated by the M кр (H·m). Consequently, the number of factors $k = 2$, and the number of experiments $n = 4$.

The torque was selected in the range M кр = 3…10, the contact area for each recess profile was calculated individually.

3 Conclusion

Simulations has shown that the rational profiles of the recessed head of the screw in terms of the stress-strain state are square (σ_{max} = 1296,2 MPa) , pentagon (σ_{max} = 1270,6 M Pa), hexagon (σ_{max} = 127 4,6 M Pa), Ryolo's triangle (σ_{max} = 1249, 64 MPa) and a rounded triangle (σ_{max} = 1309,46 MPa). From the technological point of view, with accounting for the complexity of production and the contact area between the key and the profile, the rational form of the profile of the recess for osteosynthesis screw head is a rounded triangle.

Acknowledgments

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